

RAPID FAST FIELD-CYCLING MRI USING KEYHOLE IMAGING

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Purpose

Fast Field-Cycling MRI (FFC-MRI)¹ is an emerging technique that adds a new dimension to conventional MRI by making it possible to rapidly vary B_0 during a pulse sequence. By doing this it is possible to observe how the NMR relaxation rates of biological tissues vary with magnetic field strength - information which can be employed as a useful contrast mechanism. To date we have used FFC-MRI to perform spatially-selective relaxometry using an adapted PRESS sequence² and also relaxometric imaging (a set of R_1 images at a range of field strengths) using a gradient echo sequence. Relaxometric imaging collects more information than selected-volume relaxometry but its application is limited by lengthy scan times, since the entirety of k-space is acquired at each field strength. For high-resolution imaging, or where images are collected at multiple evolution fields, scan times can become unacceptably long.

In this work we have made use of the keyhole MRI technique³ in order to speed up FFC-MRI. By collecting data for the whole of k-space at the beginning of each scan and thereafter only updating the low spatial-frequency region of k-space with each subsequent field-cycling experiment, contrast derived from the FFC technique is maintained while the scan time is dramatically reduced.

Methods

Imaging was carried out on a home-built, whole-body, field-cycling imager with a 59 mT detection field and a coaxial resistive offset magnet which provides field-cycling capabilities⁴. The system uses a commercial console (MR Solutions, U.K.).

For each experiment, reference saturation-recovery and inversion-recovery images were acquired at the detection field using a conventional spin-echo sequence. Following this, for each magnetic field of interest, the "keyhole" portion of k-space - corresponding to the central 25% of k-space was acquired using a field-cycling inversion-recovery spin-echo sequence. During the inversion recovery period B_0 was rapidly switched to a different field, referred to as the evolution field, and M_z was allowed to relax at that field for an evolution period, typically of the order of T_1 . The field was then switched back to the detection field and the imaging sequence was performed.

The data were then reconstructed by combining the initially-acquired high spatial-frequency part of k-space with the keyhole central portion of k-space, obtained at each evolution field value. In this way a full-resolution image was constructed at each evolution field value, requiring a scan time of 25% compared to conventional imaging. The technique was used to derive R_1 dispersion curves (R_1 vs Larmor frequency) from a phantom consisting of cross-linked bovine serum albumin (BSA) across a field range of 1.4 MHz to 2.5 MHz (32 mT to 59 mT).

Brain images were also collected from a volunteer (Fig 2A) in order to validate that the method generated artefact free images *in vivo*. Images were collected for evolution fields of 49 mT and 59 mT (proton Larmor frequencies of 2.1 MHz and 2.5 MHz) and from these images R_1 maps were derived.

All data processing and image reconstruction was performed using in-house software developed using MATLAB R2014a.

Results and Discussion

R_1 dispersion curves derived from BSA using the keyhole technique show excellent agreement with results obtained using a conventional full k-space scan. (Fig.1). The results show a distinct increase in R_1 at close to 2.1 MHz (49 mT). This feature is known as a quadrupole peak, and arises due to ^1H - ^{14}N cross relaxation effects, which occur at well-known field strengths. The high ^{14}N concentration typically present in protein rich tissue which leads to these peaks can be exploited to generate protein sensitive contrast in FFC-MRI images.

The R_1 maps (Fig. 2B and 2C) generated from brain images show an increase in R_1 at 49 mT, which was used to generate a ΔR_1 map (Fig. 2D) which shows a higher increase in R_1 in predominately white matter regions.

Conclusions

This work has demonstrated that the keyhole technique can readily be applied to FFC-MRI and used to obtain a 4-fold or greater speed up in scan times while still retaining the same contrast as standard FFC-MRI methods. The rich ΔR_1 contrast present in brain images indicates that FFC-MRI has potential application in the characterization of neurodegenerative conditions where subtle changes in R_1 , which may not be visible on conventional T_1 -weighted imaging, could be used as an early marker of disease.

The reduction in scan time achieved by use of the keyhole technique will significantly improve the applicability of FFC-MRI in volunteer and clinical studies, which we are currently working towards.

Acknowledgements

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References

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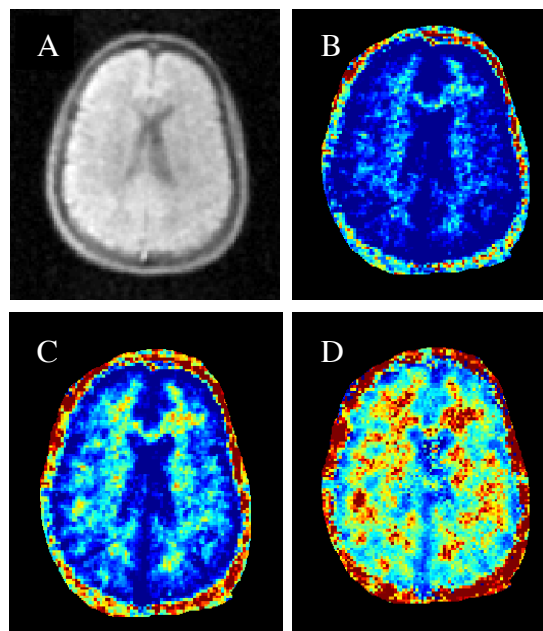


Figure 2. A: Brain image collected from a volunteer at 59 mT
B: Keyhole R_1 map collected at 59 mT
C: Keyhole R_1 map collected at 49 mT
D: ΔR_1 map generated from the subtraction of B from C. Image parameters were: matrix size = 128x128, FOV = 280 mm, THK = 15 mm, NEX = 6, TE = 30 ms, TR = 1500 ms, evolution time = 200 ms, field-cycling ramp time = 30 ms.

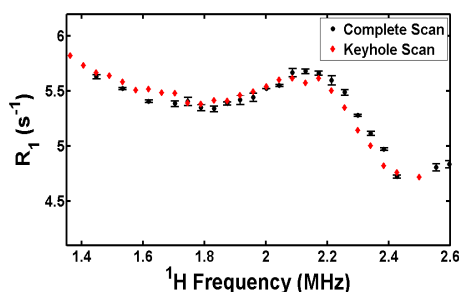


Figure 1: Dispersion curves for a phantom of cross-linked BSA obtained using the keyhole method (red diamonds) show good agreement with results obtained using a conventional field-cycling spin-echo sequence (black circles).